WL53 Table 1.

Splitting Ratio	α_{tr}
1.00	−0.3
1.10	−0.5
1.20	−0.7
1.30	−0.8
1.35	−1.0

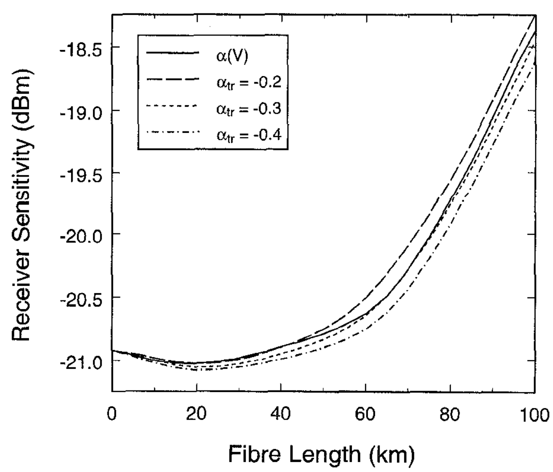
operating condition for intensity modulation with a high extinction ratio. For a splitting ratio of 1.0, the α-parameter decreases from 0 to −2.0 as the modulator changes from the off state to the on state. For a splitting ratio of 1.35, the α-parameter increases from −2.0 to −0.5 and then decreases to −2.0 as the modulator changes from the off state to the on state.

To assess the implications of the modulator chirp on system performance, a full model for the modulator is used that is based on measurements of the attenuation and phase constants for a straight section of waveguide cut from one arm of the modulator.[2] The model is included in a simulation program, which includes fiber group velocity dispersion, the nonlinear Kerr effect, receiver noise and optimization of the decision point. The transmission performance α-parameter α_{tr}[4] is obtained by replacing the full model in the system simulator with

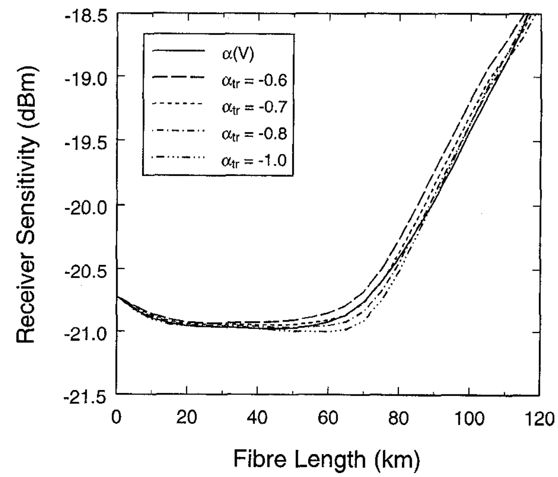
$$E(V_1, V_2) = I(V_1, V_2)^{(1+j\alpha_{tr})/2},$$

where α_{tr} is a constant and I is the intensity obtained from the full model. For a given modulator and set of operating conditions, the transmission performance α-parameter is that value of α_{tr}, which yields the best agreement with results obtained using the full model.

For a splitting ratio of 1.0, the dependence of the receiver sensitivity on fiber length is illustrated in Fig. 2 using the full model and different values of α_{tr}. In this case the transmission performance α-parameter is $\alpha_{tr} = -0.3$. Compared to Fig. 2, the results in Fig. 3 for a splitting ratio of 1.35 show less variation with α_{tr}. For fiber lengths up to 80 km, $\alpha_{tr} = -0.8$ provides good agreement with the results obtained using the full model. For lengths >80 km, $\alpha_{tr} = -1.0$ provides the best agreement. To permit the specification of a single value of α_{tr}, the fiber length that



WL53 Fig. 2. Dependence of the receiver sensitivity on fiber length for the full model (labeled $\alpha(V)$) and different values of α_{tr}. The Y-junction splitting ratio is 1.0.



WL53 Fig. 3. Dependence of the receiver sensitivity on fiber length for the full model (labeled $\alpha(V)$) and different values of α_{tr}. The Y-junction splitting ratio is 1.35.

corresponds to a 1-dB penalty in receiver sensitivity is used to specify the transmission performance α-parameter. Calculations for other values of the Y-junction splitting ratio yield the following results:[223]

For comparison, a conventional modulator (0-shift) with an optimum Y-branch splitting ratio of 0.75 has a transmission performance α-parameter of $\alpha_{tr} = -0.6$.

In summary, the dependence of the transmission performance α-parameter on the Y-junction splitting ratio has been determined for semiconductor Mach-Zehnder modulators. The results elucidate the advantages of the π-shift design compared to the conventional (0-shift) design.

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Cross talk penalty in two-channel wavelength conversion by four-wave mixing in a strained semiconductor optical amplifier

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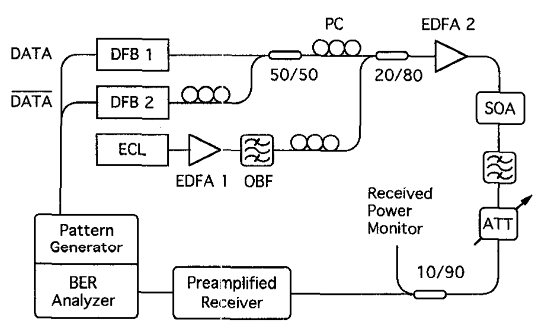
A crucial function in wavelength-division multiplexed (WDM) all-optical networks is a wavelength converter. This function enhances wavelength routing options and improves network reconfigurability. Four-wave mixing (FWM) in semiconductor optical amplifiers (SOAs) utilizing ultrafast intraband nonlinearities has been studied in recent years as a means to implement this function.[1,2] Simultaneous wavelength conversion of multiple channels has been demonstrated in an SOA[3] and in an optical fiber.[4] The issue of possible cross talk due to cross-gain saturation has been alluded to previously.[3] Here we present a systematic study of the cross talk penalty as a function of the pump-to-signal power ratio (p/s) for two 2.5-Gbit/s ASK channels separated by 1.5 nm.

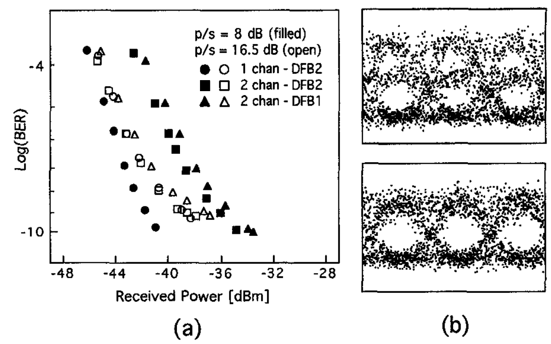
The experimental setup is shown in Fig. 1. The two signal channels are provided by directly modulated distributed feedback (DFB) lasers and the pump is provided by an external-cavity semiconductor laser. The pump is preamplified to better saturate EDFA2 and thereby minimize the amplified spontaneous emission (ASE) injected into the SOA. The pump and the two signals are then combined and amplified together. The total power coupled into the SOA biased at 150 mA is ~13 dBm. The polarization state of the pump and both signals is set to the TM polarization of the SOA using mechanical polarization controllers. At the output of the SOA, the converted signal of interest is filtered and detected using a preamplified receiver consisting of a low-noise erbium-doped fiber amplifier (EDFA) followed by an optical bandpass filter, an 11-GHz *p-i-n* receiver and a 3-GHz electrical power leveler. A Hewlett Packard bit-error-rate (BER) tester is used in the experiment.

BER measurements are performed using PRBS of length $2^7 - 1$ both for one-channel conversion using DFB2 alone, and for two-channel conversion using DFB1 and DFB2 with associated wavelength shifts of 6 and 9 nm, respectively. The pump-to-signal power ratio, measured to the individual channels at the output of the SOA, is varied from 8 to 16.5 dB. In Fig. 2(a) are shown representative BER versus received power curves for the above cases. For the smallest p/s ratio of 8 dB, there is a significant difference between one- and two-channel conversion. We have measured the parasitic cross-gain modulation on the pump for the above range of p/s ratios. Its effect on the two-channel conversion is easily seen in the eye diagrams shown in Fig. 2(b). The upper eye diagram for p/s = 8 dB shows two distinct levels for a '1' bit; the higher level corresponding to when the other channel (in this case, DFB2) is a '0' bit and the lower level resulting from a decrease in the conversion efficiency due to the compression of the pump gain when the other channel is a '1' bit. The two levels are very distinct at small p/s ratios and merge as the p/s ratio is increased.

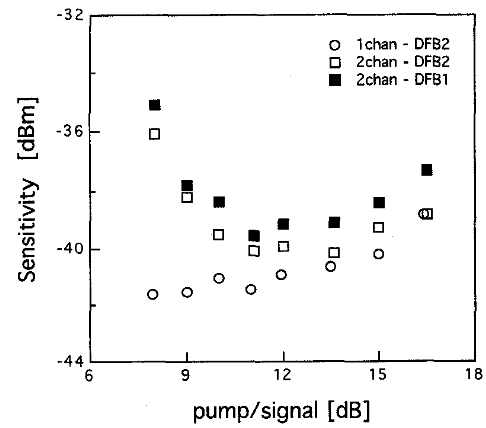
To quantify the effect of cross talk on the system performance, Fig. 3 plots the receiver sensitivity (BER = 10^{-9}) as a function of p/s ratio. Compared to the case of single-channel conversion, a significant penalty of ~6 dB is measured for two-channel conversion at the lowest p/s ratio of 8 dB. We have verified experimentally that this penalty results from the effective eye closure and the enhancement of noise power due to the presence of the second channel. At higher p/s ratios, the two-channel and one-channel sensitivities parallel each other and the difference is ≤2 dB. The observed degradation in the sensitivity with increasing p/s ratio, (even for the case of one-channel conversion) is due to the decrease in the optical signal-to-noise (SNR) of the converted signal.



WL54 Fig. 1. Schematic of the experimental setup. DFB: distributed feedback laser, ECL: external cavity laser, EDFA: erbium-doped fiber amplifier, OBF: optical bandpass filter (1 nm FWHM), PC: polarization controller, SOA: semiconductor optical amplifier, ATT: variable attenuator.



WL54 Fig. 2. (a) Representative BER vs. received power for one-channel and two-channel wavelength conversion. The received power was measured on the spectrum analyzer using a 0.5-nm resolution bandwidth. (b) Eye diagrams showing the eye closure due to parasitic cross-gain modulation in two-channel wavelength conversion. Two limiting cases in pump-to-signal power ratio of 8 dB (upper) and 16.5 dB (lower) are shown.



WL54 Fig. 3. Receiver sensitivity (BER = 10^{-9}) vs. pump-to-signal power ratio for one-channel and two-channel wavelength conversion.

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